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The use of telemedicine in radiodiagnosis in the 1920–1980s

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Abstract

In 2017, amendments to the Federal legislation on health care were adopted, which confirmed the possibility of using telemedicine technologies within the health care system of the Russian Federation. Telemedicine has been successfully used for about 150 years. Since the advent of the first electronic telecommunications, the possibilities for their medical use have been sought. This article systematises information about the history of the use of telecommunications for remote interaction in radiology and presents the way from experiments on facsimile transfer of radiographic images (the 1920–1930s) to the establishment of the teleradiology concept as a tool for solving diagnostic and organisational/managerial problems of radiology (the late 1970s). The first experiments on the remote transmission of photographic copies of X-ray images by telegraph were conducted in the mid-1920s. The first interhospital network for the exchange of medical images was launched in Canada in 1957 – a successful exchange of fluoroscopic images to improve diagnostics took place in Montreal between two hospitals. In the 1940–1960s, under J. Gershon-Cohen's supervision, several teleradiological networks ensuring the transmission of photographic copies of X-ray images for remote interpretation were launched in the United States. For the first time ever, methodological foundations of teleradiology were formulated as a tool for organising and managing public health care. The term "teleradiology" was introduced by W.S. Andrus and T.K. Bird in 1972. The same researchers carried out the first scientific assessment of the diagnostic accuracy of remote interpretation of the results of radiographic examinations. In the late 1960–1970s, television systems (cable, slow-scan, etc.) were used to broadcast medical images, and their complexity and high cost were hampering the advancement of teleradiology. However, by the early 1980s, it was convincingly shown that teleradiology significantly expanded the capabilities of health care systems, sped up diagnosis and optimised hospital resources and staff time.

Keywords

history of medicine, radiology, telemedicine, teleradiology, roentgenography

Back in 2017, amendments to the Federal legislation on health care were adopted, which confirmed the possibility of using telemedicine technologies within the health care system of the Russian Federation. Telemedicine has been successfully used for about 150 years. Since the advent of the first electronic telecommunications, the possibilities for their medical use have been sought. This article systematises information about the history of the use of telecommunications for remote interaction in radiology and presents the way from experiments on facsimile transfer of radiographic images (the 1920–1930s) to the establishment of the teleradiology concept as a tool for solving diagnostic and organisational/managerial problems of radiology (the late 1970s). The first experiments on the remote transmission of photographic copies of X-ray images by telegraph were conducted in the mid-1920s. The first interhospital network for the exchange of medical images was launched in Canada in 1957 – a successful exchange of fluoroscopic images to improve diagnostics took place in Montreal between two hospitals. In the 1940–1960s, under J. Gershon-Cohen's supervision, several teleradiological networks ensuring the transmission of photographic copies of X-ray images for remote interpretation were launched in the United States. For the first time ever, methodological foundations of teleradiology were formulated as a tool for organising and managing public health care. The term "teleradiology" was introduced by W.S. Andrus and T.K. Bird in 1972. The same researchers carried out the first scientific assessment of the diagnostic accura-

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In 2017, amendments to the federal legislation on health care were adopted, according to which the possibility of using telemedicine technologies in practical health care of the Russian Federation was legally confirmed. However, even before that, telemedicine was successfully used both in Russia and abroad (Vladzimirsky and Lebedev 2018; Levanov et al. 2011; Morozov et al. 2018) – its history goes back about 150 years (Dumanskiy et al. 2013; Vladzimirsky 2014; A Century of Telemedicine... 2016; Bashshur and Shannon 2009). Effectively, since the advent of the first electric telecommunications, many doctors and engineers have been looking for opportunities to apply new communication technologies for medical purposes. The mid-20th century is considered the 'golden age' of telemedicine. During that period, the experiments were concluded, and many technologies (videotelephony, tele-ECG, dynamic BioRadio telemetry) became routinely used in health care. Moreover, methodologies for the clinical use of telemedicine emerged, and the evaluation of its effectiveness and relevance to health care systems began. In particular, the technological and methodological foundations of telecardiology were formed in the USSR, the latter being still relevant nowadays. This article attempts to systematise information about the history of the use of telemedicine in radiology. This form of use of telemedicine technologies is known as "teleradiology".

First experiments

The first experiments on the remote transmission of diagnostic images date back to the mid-1920s. In 1926, 2 dental radiographs were telegraphed – the transmission of 2 images from New York to Chicago took 7 minutes and 20 seconds; Dr. Charles Edmund Kells (21/10/1856–07/05/1928) stated that in his article summarising 30 years of experience in the use of radiology in dentistry (Kells 1926). No conclusions were drawn about the significance of the event – C.E. Kells only noted his admiration for new technological capabilities.

Later, in 1929, the photographic prints of radiographs were re-published (Sending Dental X-rays... 1929), and contemporary authors erroneously dated the event by the time of that publication (Bashshur and Shannon 2009; Kantor 2005). However, the work of C.E. Kells allows to more accurately specify the date of the first telegraph transmission of radiographs – no later than 1926 (Kells 1926).

The later publication of photographic copies of radiographs is noted by high image quality ("Even filled root canals are clearly visible..." (Sending Dental X-rays... 1929). This service was suggested as a commercial remote consultation for dentists, but there's no data on the further development of this technology (Kells 1926).

The publications in the English-speaking media dating back to the 1930s also contain information about singular broadcasts of photographic copies of radiographs via telegraph communication.

From 1957, teleradiology began to develop in the Université de Montréal (Canada) under Professor Albert Jutras (02/10/1900–16/02/1981) in the diagnosis of diseases of the respiratory organs, gastrointestinal tract – in particular, oncological pathology of the stomach. At the same time, A. Jutras introduces such terms as "remote radiodiagnostics", "telefluoroscopy", "teleroentgen diagnostics", "videoteleradiodiagnostics" (Jutras 1959a; Jutras 1959b; Jutras and Duckett 1957; Jutras 1960). However, these terms didn't become widespread. Later, they were completely supplanted by the term "teleradiology", introduced by W.S. Andrus and T.K. Bird in 1972, which is used nowadays (Andrus and Bird 1972b).

Under A. Jutras's supervision and with the participation of Dr. Guy Duckett, a cable (coaxial) telemedicine system was organised that connected two hospitals in Montreal – Hotel Dieu and St. Jean Talon (the distance between them being approximately 10 km). A successful exchange of fluoroscopic images was realised in order to improve diagnostic solutions (Jutras 1959a; Jutras 1959b; Jutras and Duckett 1957; Jutras 1960). Unfortunately, A. Jutras's concept found only "hospital" application – in most cases, the radiological images were broadcast not between, but within, hospital institutions – that's how higher safety and quality of radiological examinations were achieved.

Telognosis

Back in the 1930s, American engineer Austin G. Cooley (09/02/1900–07/09/1993) developed an original facsimile communication system which very quickly began to be used in the New York Times to transmit photos and news. In 1947, a group of people under the leadership of Professor Jacob Gershon-Cohen (09/01/1899–06/02/1971), based upon A.G. Cooley's invention, developed a system of "remote radiographic facsimile communication using commercial telephone channels or radio" for broadcasting radiological images between hospitals in Philadelphia

and Westchester (USA). From January 1948, that system worked in the routine mode for at least 3 years, facilitating the exchange of "thousands" of images and remote consultations. The transfer of 1 image took up to 5 minutes (Gershon-Cohen and Cooley 1949; Gershon-Cohen 1950; Gershon-Cohen and Cooley 1950; Gershon-Cohen 1951; Gershon-Cohen et al. 1952; Gershon-Cohen and Cooley 1956; Gershon-Cohen et al. 1957).

As an example of successful application of the technology, a case was cited when doctors from the Einstein Medical Center (Philadelphia, USA) were able to successfully diagnose intestinal obstruction in a certain "famous" patient in Chester County Hospital (28 miles away); this emergency consultation was requested by surgeon Charles M. Kerwin (Gershon-Cohen and Cooley 1956).

The described method was called "telognosis": "The term 'telognosis' is an abbreviation of the three words 'teleo roentgen diagnosis', meaning radiographic diagnosis made by facsimile of radiographs that were transmitted by radio or telephone cable over a small or large distance" (Gershon-Cohen and Cooley 1950, p. 582).

The authors of this technology immediately pointed out its importance for "small" hospitals, medical servicing of areas with low population density, the Arctic regions, islands, and also for military medicine. Telecommunications could potentially solve the problem of high-quality and timely diagnostics (especially in cases of making urgent decisions about the need for surgical treatment). The economic rationale for the use of remote consultations in comparison with the need for the presence of a radiologist was given. In Philadelphia, the described teleradiological system was routinely used at least until 1956 (and possibly later).

In 1948, the inventors demonstrated a system for transmitting radiographs over a telephone cable and using radio communications to participants at the annual American Medical Association conference (X-ray pictures... 1948).

In 1950, a facsimile transmission of the radiographs system was deployed between the Ventnor district (Atlantic City) clinic and Philadelphia's Jewish Hospital. After a short test period, the system began to work in routine mode, supporting work in conditions of high workload of diagnostic services. After the facsimile transmission, there would be a discussion of radiographs over the same telephone channel. For several months, all radiographs taken in Atlantic City were interpreted by experts from Philadelphia. As a result, the possibility of organising the work of diagnostic departments on the basis of "telognosis" was proved, as well as the importance of this technology for the training of doctors and residents. In addition to the authors of "telognosis", Dr. M.B. Hermel participated in the work in Philadelphia, and Drs. H.S. Read and Bernard Caplan in Atlantic City (Gershon-Cohen and Cooley 1950, Gershon-Cohen and Cooley 1956).

In June 1950, also in Philadelphia, an experiment was conducted on the transmission of radiographs using a television camera and a short-wave radio communication. The absence of the need for the availability and maintenance of complex receiving equipment was deemed an advantage of this approach, a disadvantage being the high cost of transmission. However, this is how "videognosis" (short for "video diagnosis") was born – a method of teleconsulting radiographs using television communication (Gershon-Cohen 1950, Gershon-Cohen 1951).

In his publications of that time, Professor Gershon-Cohen viewed the remote diagnosis of radiological images as an essential tool for improving the quality of medical care in rural hospitals (Gershon-Cohen 1950, Gershon-Cohen et al. 1952).

In the mid-1950s, together with Dr. Harry Shay (1899–30/07/1963, USA), Professor Gershon-Cohen tested the broadcast of full-colour radiological images. In 1956, the remote transmission of radiographs via facsimile communication was organised between the Mount Sinai Hospital (New York) and Professor Gershon-Cohen's clinic in Philadelphia. In New York, Professor Bernard S. Wold (Head of the Department of Radiology) and his assistant, Sigmund A. Brahms, took part in the work. They noted the sufficient diagnostic value of the images obtained. Over the 9 years that had passed since the first approbation, telognosis hadn't become widespread. According to the results of the analysis of local projects and the New York experiment in 1956, the same reasoning was sounded about the potential possibilities of telognosis for small hospitals, isolated settlements and military bases (Sending x-ray pictures... 1956).

In 1965, J. Gershon-Cohen shared his personal experience of the use of "telognosis". During a trip to Israel, his wife got seriously ill. Considering the anamnesis, the professor sent a facsimile of her radiographs in the United States for comparison with the images taken earlier. The doctor from Philadelphia successfully compared the data of both examinations, didn't find significant dynamics and thus confirmed the diagnosis. A few days later, the patient's condition improved, and J. Gershon-Cohen once again pointed out the need for the use of telecommunications for medical services in isolated areas, developing countries and missionary centres. He also emphasised the possibility of using the newest satellite communication channels for the purposes of "telognosis" (Gershon-Cohen 1965).

Professor Jacob Gershon-Cohen is considered the creator of the concept of tele- and videognosis (effectively teleradiology), besides, he's one of the founders of mammography and thermography. This energetic man and talented scientist devoted his life to radiology – a few weeks prior to his death, he demonstrated

the capabilities of telegraphing radiographs using one of the world's first Bell Picturephone® videophones. Professor Jacob Gershon-Cohen not only developed the first sustainably operating the teleradiological system (which functioned in several locations for at least 8–9 years), but also was the first to formulate the organisational significance of the use of telemedicine technologies in radiology (Vladzimirsky 2014).

In the next decade, facsimile technology was supplanted by television technology.

The episodic return of the facsimile technology took place in the early 1970s. In Pennsylvania, physicians at Philadelphia Episcopal Hospital, Barry B. Goldberg and Jose Oscar Morales, conducted experiments on facsimile transmission of ultrasound diagnostic images taken in A, B and M modes. Later, the technology was used for the exchange of scintigraphic images (Goldberg 1972; Goldberg 1976; Morales and Goldberg 1972). Teleradiological consultations were carried out not only between hospitals – if a radiologist was at home, the diagnostic data was sent to him by telephone to his personal phone number. The teleradiological system provided effective training for medical personnel in situ (especially the nursing staff), and allowed for quick and high-quality interpretation of diagnostic data by an expert doctor. Dr. Barry B Goldberg wrote: "This technology show promise for increasing the individual productivity of a doctor and allows the introduction of ultrasound diagnostics in hospitals that are too small to contain a trained doctor" (Goldberg 1972, p. 459). However, technical difficulties and the lack of a guarantee of obtaining an "output" image of sufficient quality prevented widespread use of the method.

Television and radiology

In the 1960s, the facsimile technology for the transmission of diagnostic images gave way to the television technology. During this period, the intensive development of telemedicine networks based upon video conferencing began. Due to this, remote consultations were widely spread in psychiatry, surgery, and also distance education in medicine reached a new level of development (Dumanskiy et al. 2013; Vladzimirsky 2014; A Century of Telemedicine... 2016; Bashshur and Shannon 2009). The first means of videoconferencing based upon television systems were widely and successfully used for broadcasting images of the results of radiological examinations placed on negatoscopes (Hesca Feedback 2000). The technology was used in medical organisations in Canada, Holland, USA, Finland, Sweden and Japan.

In particular, in 1962–1963 in Holland, television communications were used at Leiden University by Dr. Wim Herstel, a member of the department of radiology at the university clinic (Herstel 1962; Herstel 1963). In 1969 in Finland, national television technologies were used to transfer radiographic images between the universities of Oulu and Helsinki (about 600 km apart). The quality of the images obtained was found to be satisfactory for the initial diagnosis, but the extremely high cost of the technology prevented its introduction into everyday clinical practice (Reponen 2010; Reponen 2004). It's worth noting that there was no scientific publication of the results of this pilot project (Soila 1970).

In the 1970s in Massachusetts, the famous telemedicine network was organised, the core of which was the Massachusetts General Hospital. Based upon this network, vast experience in conducting telemedical consultations was accumulated, scientific studies to assess the diagnostic capabilities and effectiveness of telemedicine were carried out, and the methodology for the use of video conferencing was systematised for the first time (Vladzimirsky 2014; Bashshur and Shannon 2009).

The founders of this telemedicine network, Timothy Kenneth Bird (1918–13/02/1991) and W. Scott Andrus (10/08/1938–19/05/2013), introduced the term "teleradiology" in 1972 (Andrus and Bird 1972b), and later conducted a scientific assessment of the reliability and diagnostic value of remote interpretation of radiographs via video conferencing (for the first time ever, the values of sensitivity and specificity of telemedicine diagnostics on an array of 198 radiological images of the chest, musculoskeletal and genitourinary systems were obtained using the analysis of characteristic curves) (Andrus and Bird 1972a; Andrus et al. 1975a; Andrus et al. 1975b; Murphy et al. 1970).

W. Scott Andrus and Kenneth T. Bird very succinctly formulated the possibilities of teleradiology from the point of view of improving the quality of the health care system; they wrote: "Teleradiology, or remote radiological practice, offers a technological approach to solving many of the logistical problems of radiology and medicine. It[1] reduces the distance between the radiologist and radiograph" (Andrus and Bird 1972b, p. 655).

In the autumn of 1973, a project on the transmission of radiological images through slow-scan television began operating at the University of Nebraska (USA). The telemedicine system has united the Jenny M. Melham Memorial Medical Center in Broken Bow and the University of Nebraska Medical Center in Omaha. For data transmission, standard telephone cable channels, special modems and television equipment (for transmission and reception) were used. An interesting fact is that the teleradiological system was deployed to replace the "postal-paper" interpretations of radiographs (at the Broken Bow Hospital there were no staff radiologists, and as a result, all radiological examinations data were sent by mail to the university

[1] Meaning the telemedicine system.

clinic for interpretations, and then, also by mail, returned with answers; the whole cycle took 4 days). On average, approximately 400 teleradiological consultations were conducted per month; later experiments were conducted on the transmission via slow-scanning television of other types of medical information (ECG, documents, photographs of microscope slides, skin diseases and certain types of pathology of the eye and oral cavity) (Park 1974).

Later on, slow-scan television was used as a teleradiology tool in a number of telemedicine projects and networks in North America (USA, Canada), Europe and Asia (particularly in Japan) (Yoshimura 1975). Experiments were conducted on wireless image transmission (Piping patients... 1968). These technologies were also used in "maritime telemedicine" for transmitting images of radiographs from sea ships to coastal hospitals (Rasmussen et al. 1977). The creators of the telemedicine network (based upon the communication channels of the Hermes satellite) in the Arctic regions of Canada claimed that teleradiographic and telefluoroscopic consultations were effective in 90% of cases (Carey et al. 1979).

Teleradiology and the personnel problems solution

In 1973, perhaps for the first time in the world, it was proposed to use telemedicine and computer technologies to correct personnel imbalances in the field of nuclear medicine. Dr. James W. Fletcher, Dr. Robert M. Donati, medical physicist Francis Kennedy Herbig and James L. Daly implemented the concept of "information system for nuclear medicine". A network of the expert centre (John Cochrane University Hospital, St Louis) and three veteran hospitals located in rural Missouri and Illinois were built. All radioisotope studies conducted in remote hospitals and the accompanying clinical data were centrally sent to the expert centre for interpretation and quality control at the end of the working day. The system allowed to successfully implement radionuclide diagnostics in small hospitals that didn't have a full-time specialist (Daly et al. 1975).

A similar network was deployed in Missouri (USA). By 1976 in St Louis, there was a teleradiological network between the medical centre for veterans and several rural hospitals. At the end of each working day, the technical staff transmitted the results of all the examinations conducted to the expert centre for computer processing. Interpretations and conclusions were teletyped the next day (Bennett 1978).

In 1974–1977, special hardware solutions for remote transmission of the results of X-ray and radionuclide examinations were intensively designed (Jelaso et al. 1978; Krause et al. 1975; Maxfield et al. 1975). Despite the encouraging results of tests, such technologies didn't gain wide acceptance (apparently, due to high cost and inefficiency for routine use).

However, the success of engineering is of less interest to us than the evolution of methodologies.

From the point of view of the development of telemedicine methodology, the use of teleradiology for educational and methodological support during the introduction of new diagnostic technologies became an important point. For example, in 1969–1973 in Los Angeles (USA), employees of the Department of Radiology at the University of California provided remote support for their colleagues from Queen of Angels hospital during the introduction of nuclear medicine (radionuclide research methods). Teleconsultations were conducted in real time; images were visualised using a television camera and broadcast over the air (decimetre waves); parallel discussions were conducted by telephone. Diagnostic and technological efficiency were studied on the material of 100 clinical cases. A conclusion about the feasibility of using the technology for remote interpretation of the results of radionuclide examinations was made; however, the limitations of the method for conventional chest radiographs were noted (Vladzimirsky 2014, Telecommunication... 1971).

In 1971, the Department of Radiology at the University of California collaborated with the Department of Nuclear Medicine at the St. Agnes Hospital (Fresno, California, USA) under the leadership of Dr. Howard F. Corbus. Scintigrams of the brain, organs of the chest and others could be broadcast using a slow-scan television system. Teleconsultations were conducted to support decision-making and real time differential diagnostics. The process of remote interaction included a preliminary phone call with the provision of clinical data, sending images, interpretation and final discussion by telephone. Within an hour of such a process, doctors were able to consider data from 4–5 patients (Telecommunication... 1971, Webber and Corbus 1972).

A similar organisational model of teleradiology in the field of nuclear medicine was applied in the UK almost 10 years later. A network was established between 3 medical centres (Kent and Canterbury hospitals, St Thomas' and Charing Cross). In a pilot project, experts evaluated the technical capabilities of remote support of small departments using the material of several hundred images. Data transmission was carried out via telephone communication channels through modems and computers. Technical aspects of compatibility, approaches to error elimination, etc., were evaluated (Corfield et al. 1981).

So, by the early 1980s, it was convincingly shown that teleradiology significantly expanded the capabilities of health systems, sped up diagnosis, optimised hospital resources and medical staff working hours (Curtis et al. 1983; Gayler et al. 1979; Gayler et al. 1981; Pagé et al.

1981; Diagnosis by Television... 1950; Keen 1984). In fact, the conceptual foundations of teleradiology were formulated, but it was not widely adopted (compared to other tools and methods). The constraining factors were, on one hand, the rather dubious diagnostic value of images (from the point of view of mass use) demonstrated through interactive video conferencing and slow-scan television, and on the other hand, the complexity of operation and the extremely high cost of equipment for digitising and broadcasting images.

In the mid-1980s, thanks to the development of computer technology and the Internet, a fundamentally new stage in the development of telemedicine began. This led to the fact that nowadays, as a result of the rapid progress of both diagnostic and telecommunication digital technologies, teleradiology has become one of the standard radiological diagnostic tools.

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